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Fine Pore (Fine Bubble) Aeration of Municipal Wastewaters

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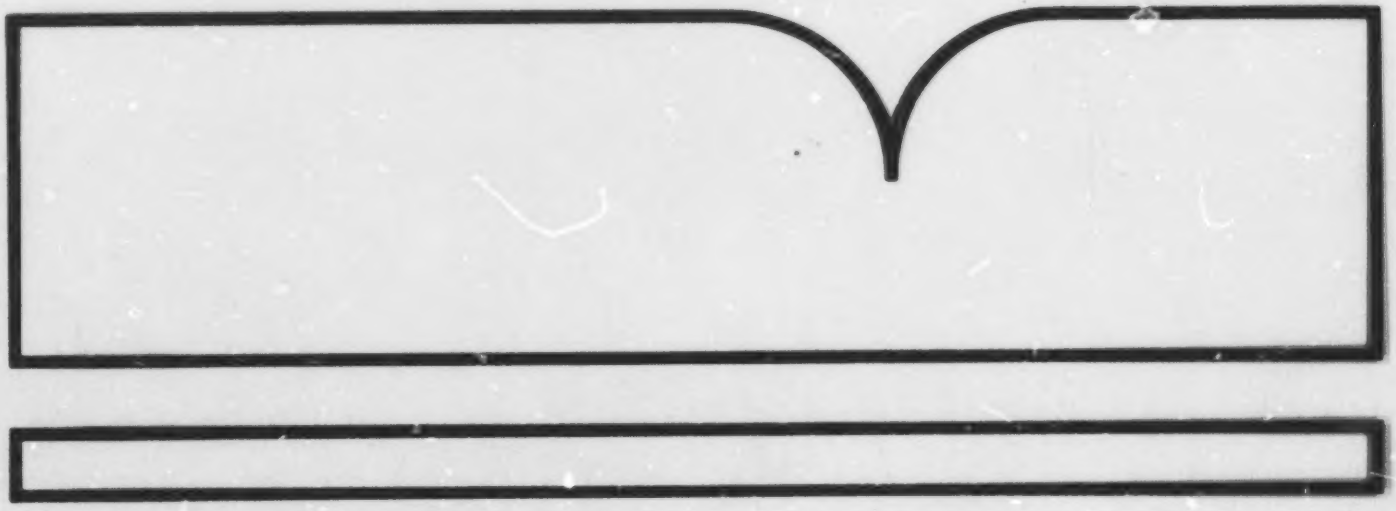

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16. ABSTRACT

This paper summarizes the current information on fine pore aeration systems. Types of media, types of diffusers, piping and layout, characteristics of diffusers, clear and process water performance, operation and maintenance, diffuser fouling and economic analyses are reviewed. The paper is based on a report titled "Interim Guidance for Aeration with Fine Pore (Fine Bubble) Diffusers" which is developed jointly by the U.S. EPA and the American Society of Civil Engineers and published in the fall of 1985.

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by

Richard C. Brenner
Atal E. Eralp
Wastewater Research Division
Water Engineering Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

William C. Boyle
Department of Civil & Environmental Engineering
University of Wisconsin
Madison, Wisconsin 53706

WATER ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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INTRODUCTION

Aerobic biological processes continue to be one of the more popular methods employed to treat municipal and industrial wastewaters. The supply of oxygen to the biomass in activated sludge systems and aerated lagoons represents the single largest energy consumer in wastewater treatment facilities. Recent studies indicate that from 50 to 90 percent of the net power demand for a treatment plant lies within the aeration system. A general survey of data made available in 1982 on municipal and industrial wastewater treatment installations suggests that on the North American continent there are approximately 1.3 million kw (1.75 million hp) of aeration equipment in place at an installed value of 0.6 to 0.8 billion dollars. Operating costs for these systems may be expected to be about 0.6 billion dollars/yr.

Originally, oxygen was diffused into wastewater through perforated pipes located at the bottom of the aeration tank. The development of the porous plate was considered an important advance in the diffused aeration process because of the higher oxygen transfer efficiency offered by this fine pore device. Porous diffuser plates were used as early as 1916 and became the most popular method of aeration in the 1930's and 1940's. It was clear shortly after the development of porous diffusers that clogging could be a problem. Early work on clogging led to the use of coarser media and eventually to large orifice devices. The use of mechanical aeration devices was another answer to the clogging problem, although these devices were normally applied to small treatment facilities and industrial waste applications.

The energy crisis of the early 1970's rekindled interest and awareness within the environmental engineering community relative to the efficiency of oxygen transfer systems. As a result, the fine pore diffusion of air has gained renewed popularity as a very competitive system. Yet, considerable concern has been registered regarding the performance and maintenance of fine pore diffusion systems owing to their susceptibility to clogging. Diffuser clogging, if severe, may lead to deterioration of aeration efficiency and corresponding escalation of power costs. Furthermore, troublesome maintenance of diffusers may consume considerable amounts of operator time and plant operating budget.

In this paper a summary of the current information on fine pore aeration systems is presented. It is based on a comprehensive report titled "Interim Guidance for Aeration with fine Pore (Fine Bubble) Diffusers" which was developed jointly by the U.S. Environmental Protection Agency (USEPA) and the American Society of Civil Engineers (ASCE). It will be published in the fall of 1985.

"Fine bubble" diffused aeration is elusive and difficult to define specifically. The term "fine pore" is preferred instead of "fine bubble" to more nearly reflect the porous characteristics of the diffusers themselves. Typically, fine pore diffusion devices will produce a headloss due to surface tension in clean water of greater than about 5 cm water gauge.

TYPES OF FINE PORE DIFFUSION MEDIA

A number of porous materials capable of serving as effective aeration devices are marketed today. In general, a wide range of products that were initially developed to filter air or liquid have also been found to act as satisfactory air diffusion devices. Because of cost and specific characteristics, only a few of these materials are actually being used in the wastewater treatment field.

Ceramic Materials

The oldest and still the most common type of porous material on the market is the ceramic type. It consists of rounded or irregular-shaped mineral particles bonded together to produce a network of interconnecting passageways through which compressed air flows. As the air emerges from the surface pore, pore size, surface tension, and air flow rate interact to produce a characteristic bubble size.

Ceramic diffusers manufactured from glass- or resin-bonded silica or alumina are available. The two most popular materials are glass-fused silica and glass-fused alumina.

Plastic Materials

A more recent development in the fine pore diffuser field is the use of porous plastic materials. As with the ceramics, a material is created consisting of a number of interconnecting channels or pores through which compressed air can pass. Advantages of the plastic material over aluminum oxide are its lighter weight, lower cost, better durability, and, depending on the actual material, greater resistance to breakage. Disadvantages include its reduced strength and susceptibility to creep.

A few minor differences exist between the two types of material. However, for wastewater treatment applications, the performance of both silica and alumina is expected to be approximately the same.

Porous plastics are made from a number of thermoplastic polymers including polyethylene, polypropylene, polyvinylidene fluoride, ethylene-vinyl acetate, styrene-acrylonitrile, and polytetrafluoroethylene. Probably the two most common types of plastic materials in use are high density polyethylene (PE) and stryene-acrylonitrile (SAN).

Flexible Sheaths

Flexible diffusers have been in use for approximately 40 years. They initially were referred to as "sock" diffusers and were made from materials such as plastic, synthetic fabric cord, or woven cloth. Because of the woven type sheaths, a metallic or plastic core material was necessary for structural support. Although sock diffusers were capable of achieving relatively high oxygen transfer rates, fouling problems were often severe. Today, there is essentially no market for the early sock design.

Within the last several years, a new type of flexible diffuser has been introduced. It consists of a thin flexible sheath made from soft plastic or rubber. Air passages are created by punching minute slots in the sheath material. When the air is turned on, the sheath expands. Each slot acts as a variable aperture opening; the higher the air flow rate the greater the opening. The sheath material is supported by a tubalar frame.

This new generation of flexible diffusers has been in operation at a number of facilities for the last several years. The new sheath material has reduced the severe fouling problems associated with the earlier woven fabric design. The manufacturer estimates sheath life to be about 5 years.

TYPES OF FINE PORE DIFFUSERS

Today, there are four general shapes of fine pore diffusers on the market: plates, tubes, domes and discs.

Plate Diffusers

Plates are typically 30 cm square and 2.5 to 3.8 cm thick. They are manufactured from either glass-bonded silica or glass bonded aluminum oxide. Fine pore plates were used almost exclusively as the method of air diffusion in the early activated sludge plants through the 1920's. Today, other than in some of the original plants, fine pore plates are not often specified and installed.

Tube Diffusers

Like the plates, fine pore tubes have been used in wastewater treatment for a number of years. The early tubes, Saran wound or made from aluminum oxide, have been followed by the introduction of SAN copolymer, porous PE, and, most recently, the new generation of flexible media.

All the tube diffusers on the market are of the same general shape. Typically, the media portion is 50 to 60 cm long and has an O.D. of 6.4 to 7.6 cm.

Dome Diffusers

The fine pore dome diffuser was developed in Europe in the 1950's and introduced in the U.S. market in the early 1970's. Long considered the standard in England and some parts of Europe, domes are now installed in a number of U.S. plants.

The dome diffuser is essentially a circular disc with a downward-turned edge. Currently, these diffusers are 18 cm in diameter and 3.8 cm high. The media is approximately 15 m thick on the edges and 19 mm on the top or flat surface. Domes presently are being made only of aluminum oxide.

Disc Diffusers

Disc diffusers are a relatively recent development. Discs are flat, or relatively so, and are differentiated from dome diffusers in that they do not

include a downward-turned peripheral edge. While the dome design is relatively standard, currently available disc diffusers differ in size, shape, method of attachment, and type of material.

Disc diffusers are available in diameters that range from approximately 18 to 24 cm and thicknesses of 13 to 19 mm. With the exception of one design, all discs consist of two flat parallel surfaces.

AIR PIPING AND DIFFUSER LAYOUT

Fine bubble plates are normally installed in either total floor coverage or spiral roll. Total floor arrangements may include closely spaced rows (transverse or longitudinal) or incorporated in a ridge and furrow design. Total floor layouts produce higher oxygen transfer efficiencies than the more efficient mixing spiral roll.

Most tube diffusers can be attached to existing left out assemblies which make them especially suited for retrofit. They are often installed parallel along one or both long sides of the aeration basin. New designs, however, employ cross roll or full floor coverage patterns.

Both domes and discs are installed in a total floor coverage or grid type pattern. In some cases where mixing may control the design (near the end of long narrow tanks), the diffusers can be placed in tightly spaced rows along the side or middle of the basin to create a spiral type mixing pattern. The diffusers are usually mounted as close to the tank floor as possible, within 23 cm of highest point being typical.

CHARACTERISTICS OF FINE PORE MEDIA

The parameters which have been used by design engineers to characterize fine pore media include permeability, uniformity, dynamic wet pressure, strength, chemical stability, resistance to heat and density.

Permeability is a measure of a porous medium's frictional resistance to flow. It is an empirical rating that relates flux rate to pressure loss and pore size and/or pore volume. The permeability measurement, however, does not provide a true basis for comparison of media performance because the same permeability rating could be obtained from a diffuser with a few relatively large pores or a multitude of small pores. Also, two diffusers with exactly the same pore structure would have different ratings if of different thickness.

Uniformity of individual diffusers and the entire aeration system is of extreme importance if high oxygen transfer efficiency (OTE) is to be attained. On an individual basis, the diffuser must be capable of delivering uniform air distribution across the entire surface of its media. If dead spots exist, chemical or biological foulants may form and eventually lead to premature fouling of the diffuser. Also, if small areas of extremely high air flux rate are present, larger bubbles may form and OTE will increase.

Dynamic wet pressure (DWP) is an important consideration in evaluating and selecting a porous media. DWP is defined as the operating headloss

across diffuser media submerged in water at a specified air flow rate per diffuser. As a general rule, the smaller the bubble size, the higher the DWP. While smaller bubbles may increase OTE, the additional power required to overcome the higher headloss may negate any potential savings.

Diffusion media must be strong enough to withstand static head of water over the diffuser, forces applied to media under construction, and stresses of reasonable handling and shipping. All the materials described herein are impervious to normal concentrations of chemicals used in wastewater treatment including periodic exposure to strong acid solutions used for cleaning. Temperature resistance is not a problem under normal operating conditions. Density is of concern where diffusers are to be lifted out of the tank for routine maintenance.

PERFORMANCE OF FINE PORE DIFFUSERS

Higher oxygen transfer efficiency and therefore energy conservation is one of the main advantages of fine bubble aerators over coarse bubble aeration. Determination of this improved oxygen transfer and report data in a uniform fashion has been the subject of many research efforts. Clean water and process water performance of fine pore diffusers and the standardization of the tests in determining the performance is reviewed in detail in the upcoming USEPA/ASCE Guidance Manual. Following is a brief presentation on the performance of fine pore diffusers.

Clean Water Performance

The results of clean water oxygen transfer tests are reported in a standardized form as either standard oxygen transfer efficiency (SOTE), standard oxygen transfer rate (SOTR), or standard aeration efficiency (SAE) as shown in Table 1. The standard conditions for reporting clean water tests are also delineated in Table 1.

Typical SOTEs for fine pore diffused air systems are presented in Table 2. These data are reported for a diffuser submergence of 4.6 m. The effect of diffuser type, placement, and air flow rate per diffuser are clearly delineated from this summary of eight different clean water studies. In general, it can be observed that ceramic domes and discs demonstrate slightly higher clean water transfer efficiencies than typical porous plastic tubes or flexible sheath tubes in a grid placement. Both tubes and discs/domes are significantly superior to all coarse bubble placements.

Figure 1 also demonstrates the effect of air flow rate per diffuser on oxygen transfer efficiency. Whereas domes and discs in a grid placement show a dramatic decrease in SOTE with increased air flow, plastic porous media, and flexible tubes exhibit an intermediate effect and coarse bubble patterns are relatively unaffected by gas flow rate with some indication of increasing SOTE at the higher gas flows.

The performance of diffusers under clean water test conditions is dependent on a number of factors in addition to those standardized in the calculations of SOTE, SOTR, and SAE. Among the important factors are:

TABLE 1. Standard Equations for Clean Water Oxygen Transfer Tests

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Standard Conditions:

DO	= 0.0 mg/L	α	= 1.0
Temperature	= 20°C	β	= 1.0
Pressure	= 1.00 atm		

Standard Oxygen Transfer Rate (SOTR) - mass/time

$$SOTR = K_L a_{20} \, V \, C^*_{\infty 20}$$

Standard Oxygen Transfer Efficiency (SOTE)

$$SOTE = \frac{\text{Mass Transferred}}{\text{Mass Supplied}} \times 100$$

$$= \frac{SOTR}{Y_R \, q_s}$$

Standard Aeration Efficiency (SAE) - mass/time, power

$$SAE = \frac{SOTR}{\text{Power Input}}$$ (specified as delivered, brake, wire, or total wire)

$K_L a$ = apparent volumetric mass transfer coefficient in clean water, time $^{-1}$

$K_L a_{20}$ = $K_L a$ @ 20°C, time $^{-1}$

V = volume of water, length^3

Y_R = mole fraction of oxygen delivered

= density of oxygen at actual temperature and pressure, mass/length^3

q_s = volumetric air flow rate, length^3/time

$C^*_{\infty 20}$ = equilibrium DO saturation concentration attained at infinite time for given diffusion device at 20°C and 1 atm, mass/length^3

TABLE 2. Clean Water Oxygen Transfer Efficiency Comparison For Selected Diffusers

Diffuser Type & Placement	Air Flow Rate (scfm/diffuser)	SOTE (%) at 15-ft Submergence
Ceramic Discs-Grid	0.6-2.9	25-36
Ceramic Domes-Grid	0.5-2.5	27-39
Porous Plastic Tubes		
Grid	2.4-4.0	28-32
Dual spiral roll	3.0-9.7	18-28
Single spiral roll	2.0-12.0	13-25
Flexible Sheath Tubes		
Grid	1-4	22-29
Quarter points	2-6	19-24
Single spiral roll	2-6	15-19
Coarse Bubble Diffusers		
Dual spiral roll	3.3-9.9	12-13
Mid-width	4.2-45	10-13
Single spiral roll	10-35	9-12

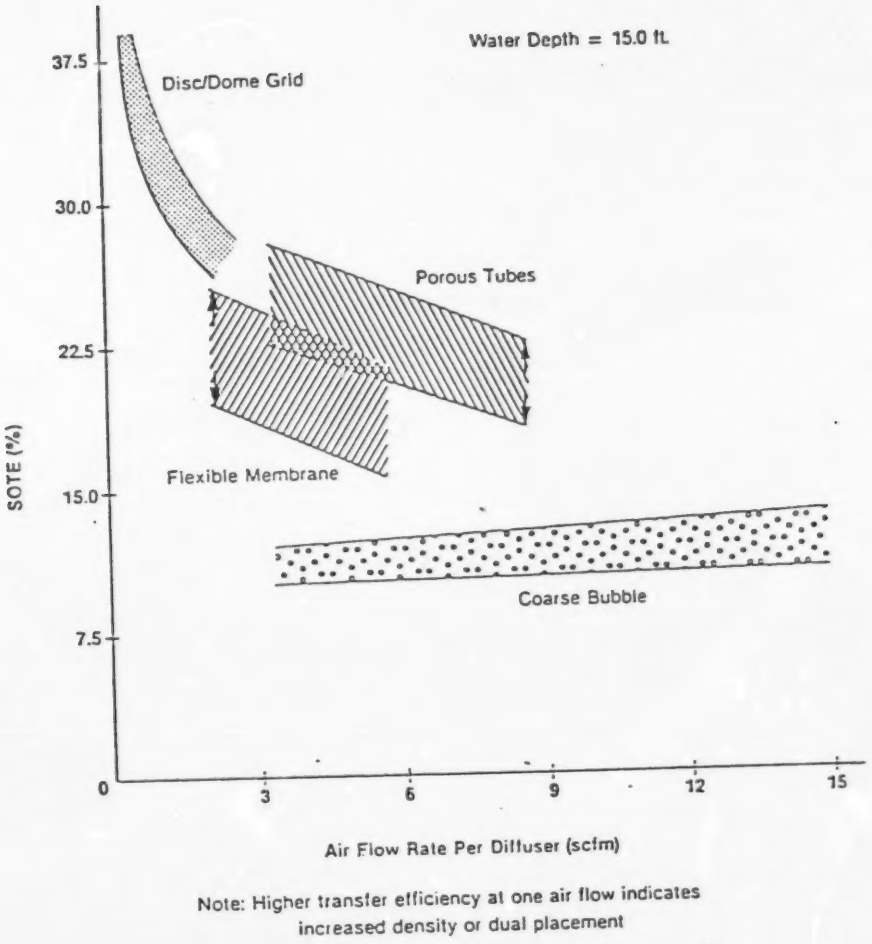

Figure 1. Oxygen transfer efficiency vs air flow rate.

- diffuser type (material, shape, and size),
- diffuser placement and density (area served per diffuser),
- gas flow rate per diffuser, and
- diffuser submergence and tank geometry.

Relative importance of these factors is not discussed here.

PROCESS WATER PERFORMANCE

Although a substantial data base exists for the clean water performance of the diffused aeration systems considered in this report, the process water oxygen transfer data base is much more limited. Since oxygen transfer performance under field conditions is really the ultimate goal, expansion of the latter data base is needed. The standard clean water transfer rate (SOTR), as measured at 20°C with a zero residual DO concentration, may be related to actual field conditions (OTR_f) according to the following equations:

$$OTR_f = \alpha SOTR \frac{(\beta \tau \Omega C^*_{\infty 20} - C)}{C^*_{\infty 20}} \theta^{(T-20)}$$

Where: $\alpha = \frac{K_l a f}{K_l a}$

$\beta = \frac{C^* \text{ (field)}}{C^* \text{ (clean water)}}$

$\tau = \frac{C_{sT}}{C_{s20}}$

$\Omega = \frac{P_b + d_e - P_{v20}}{P_s + d_e - P_{v20}}$

$\theta^{(T-20)} = \frac{K_l a_T}{K_L a_{20}}$

$K_L a_f$ = apparent volumetric mass transfer coefficient in process water

C^* = equilibrium DO saturation concentration corresponding to a given partial pressure of oxygen, temperature, and volume

C_{sT} = surface DO saturation concentration at 1 atm total pressure, 100 percent relative humidity, and temperature T

C_{s20} = surface DO saturation concentration at 1 atm total pressure, 100 percent relative humidity, and a temperature of 20°C

P_b = base pressure

P_s = standard pressure of 1 atm

P_{v20} = vapor pressure of water at a temperature of 20°C

d_e = effective saturation depth at infinite time

Alpha is probably the most controversial and researched parameter used in translating clean water oxygen transfer data to actual field performance. Variables affecting the value of alpha include aerator type, nature of wastewater contaminants, position within the treatment scheme, process loading rate, bulk liquid DO, water depth, and air flow rate. Coherent data on alpha values for various aeration devices are limited. Reported alpha values from 0.2 to 1.53 have been published. Because much of the reported alpha data was obtained from bench-scale units (which did not properly simulate mixing and K_La levels, aerator type, water depth, and/or the geometry effects of their full-scale counterparts), these data are of questionable value. Reliable full-scale test procedures for use under process conditions, coupled with clean water performance data, are required to overcome these deficiencies.

Additionally, the performance of diffused aeration systems under process conditions is affected by a myriad of factors, some of the more important of which are:

- wastewater characteristics,
- process type and flow regime,
- loading conditions,
- basin geometry,
- diffuser placement and performance characteristics,
- changes in performance due to fouling,
- mixed liquor DO control and air suppy flexibility,
- mechanical integrity of the system,
- operator expertise, and
- quality of preventive maintenance.

In 1981, the ASCE Oxygen Transfer Standards Subcommittee undertook a seven-site study to evaluate, in parallel, four principal methods for estimating oxygen transfer under process conditions. These methods include the steady state method, the nonsteady state method, an off-gas analysis procedure, and two inert gas tracer techniques.

The details of these techniques and the preliminary field scale research results using these techniques are presented in the U.S. EPA/ASCE guidance manual. Process water oxygen transfer performance data from 13 evaluations at various sites employing a variety of aeration systems are presented in Table 3. Each data set represents the observed performance of a particular system over a period of several hours only and is not suitable for the design of similar systems. The intent of this table is to give the reader a general feeling for the range in performance of the systems listed under a variety of operating conditions.

The review of all the available data indicates, however, that gaps in the current data base still exist for which additional studies are needed to address designers' concerns.

OPERATION AND MAINTENANCE

In order to obtain the advantages of fine pore diffusers fully, the systems should be constructed or retrofitted with operation and maintenance

TABLE 3. In Process Oxygen Transfer Data

Site	System	Flow Regime	In Process $SOTE_f$ (%)		Apparent Alpha		Mean Air Flux Rate ($L/m^2/sec$)
			Average	Range	Est. Mean	Range	
Madison, WI	Ceramic Grid	Step Feed	17.8	12.6/26.2	0.64	.42/.98	1.42
Madison, WI	Ceramic & SAN Tubes	Step Feed	11.0	7.5/13.4	0.62	.46/.85	2.69
Madison, WI	Wide Band - Coarse Bubble	Step Feed	10.0	7.9/10.9	1.07	.83/1.19	0.53 2.69
Whittier-Narrows, CA	Ceramic Grid	Plug Flow	11.2	9.3/15.2	0.45	.35/.60	1.07
Whittier-Narrows, CA	Jet	Plug Flow	9.4	7.8/10.8	0.58	.48/.72	1.88
Brandon, WI	Jet	CSTR	10.9	9.7/12.1	0.45	.40/.50	0.66
Brandon, WI	Jet	CSTR	7.5	7.4/7.7	0.47	.46/.48	1.98
Orlando, FL	Wide Band - Coarse Bubble	CSTR	7.6	6.8/8.4	0.75	.67/.83	4.67
Seymour, WI	Ceramic Grid	Plug Flow	16.5	12.0/18.8	0.66	.49/.75	0.35
Lakewood, OH	Ceramic Grid	Plug Flow	14.5	12.4/15.9	0.52	.44/.57	0.71
Lakewood, OH	Ceramic Grid	Plug Flow	8.9	7.0/11.1	0.31	.26/.37	0.46
Brewery	Ceramic Grid	CSTR	14.2	12.5/15.2	0.37	.32/.37	1.52
Brewery	Static Aerator	CSTR	7.4	5.7/8.8	0.50	.36/.51	2.69

in mind. The principal objective in the design of fine pore aeration sytems should be to provide a system with the lowest possible life cycle cost, maintaining an optimun balance between capital and long-term O&M expenditures. Since long-term O&M characteristics will generally be determined by the capabilities and constraints originally designed into such systems, it is important that due consideration be given during design to anticipated O&M requirements. In some cases, relatively minor capital expenses can lead to significant reductions in overall cost by reducing those requirements.

Proper care in process design, materials selection, aeration basin design, air supply design, and aeration system installation during design can lead to significant long-term benefits.

Although not complete, there is a vast amount of practical information available for the designers. The reader is referred to the original references listed in the USEPA/ASCE Guidance Manual.

DIFFUSER FOULING

A major concern in the maintenance is the fouling of the diffuser. The rate of fouling has historically been gauged by the rise of back pressure while in service, although this measure is not always accurate. Over the years many types of fouling have been identified by the investigators. The main types are listed below:

Air Side

- Dust and dirt from unfiltered air
- Oil from compressors or viscous air filters
- Rust and scale from air pipe corrosion
- Construction debris due to poor cleanup
- Wastewater solids entering through diffusers or pipe leaks

Liquor Side

- Fibrous material attached to sharp edges
- Inorganic fines entering media at low or zero air pressure
- Organic solids entering media at low or zero air pressure
- Oils or greases in wastewater
- Precipitated deposits, including iron and carbonates
- Biological growth on diffuser media

Close process monitoring and preventive maintenance are known to help reduce the rate of fouling of fine pore diffusers. Fouling will still occur, however, and the diffusers will have to be cleaned periodically. A number of different cleaning procedures have been developed, identified, and applied. The main ones are:

Ex-Situ

- Refiring
- Silicate-phosphate washing
- Alkaline washing

- Acid washing
- Detergent washing

In-Situ

- Acid washing
- Flaming
- High pressure water hosing
- Withholding influent (creating endogenous conditions)
- Sandblasting
- Chlorine washing
- Air bumping (air turned off and on)
- Steam cleaning
- Gasoline washing
- Drying

ECONOMIC ANALYSIS

The factors used in the design of a fine pore diffuser system also comprise the basis for determining its economic viability. Installation of fine pore equipment should be undertaken only if a reasonable return on investment can be foreseen. The cost effectiveness of fine pore retrofit is most appropriately based on present day flow and loading to the plant rather than anticipated future increases and should consider the total present worth of the investment as well as "simple payback."

Simple payback indicates payback in years but neglects the effects of inflation and the time value of money. A more realistic approach to economic evaluation is based on the present worth of the cost savings of the retrofit project at some time in the future. This type of analysis accounts for the fact that energy costs and maintenance costs will increase due to inflation and that the money invested in a fine pore retrofit project would provide a return if used for other types of investments, as well.

A more sophisticated determination which would allow energy costs to increase at a faster rate than the general inflation rate can also be performed. An estimate of the energy cost inflation rate should be made in conjunction with the local power utility as this phenomenon could vary widely. As the payback period becomes longer, these anslyses become vary sensitive to the assumptions made for inflation and discount rates. If the apparent payback period exceeds five or six years, the assumptions used should be reviewed. If they are found to be reasonable andprudent, the economic viability of the retrofit should be scrutinized carefully.

ONGOING STUDIES

Significant progress has been made in the last 5 years to better delineate the design, testing, maintenance, and control requirements of fine pore diffused aeration systems. However, many gaps still exist in our complete understanding of these systems. For example:

- How do the various fine pore aeration systems perform in process waters, both in absolute terms and relative to each other?

- How can clean water test data best be translated to field conditions?

- What is the behavior of fine pore diffusers with respect to long-term, liquid-side fouling?

- What strategies will cost effectively control and maintain these systems while still yielding acceptably high field OTEs?

Several research projects are presently under way in the United States, Canada, and the United Kingdom addressing the above and other questions related to fine pore aeration system design, performance, operation, maintenance, installation, control, and costs.

SUMMARY

Fine pore diffused aeration is gaining acceptance in the U.S. as a competitive system. The information to select, install, and operate an optimum fine pore diffused aeration system to meet oxygen requirements of biological systems is now available. An Interim Guidance for Aeration With Fine Pore (Fine Bubble) Diffusers will be published jointly by the U.S. EPA and the ASCE in the fall of 1985.